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A SEQUENCE OF TORNADO DAMAGE PATTERNS

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ABSTRACT

An investigation is made of the patterns of damage associated with a series of tornadoes in west-central Wisconsin on June 4, 1958. Three flow models are presented to account for the different patterns exhibited in different portions of the paths.

1. INTRODUCTION

The system of tornadoes which struck west-central Wisconsin on the afternoon of June 4, 1958, passed over extensive forest areas, and left a sequence of damage patterns perhaps unique in recent years.[1] The storm system as a whole produced at least five major damage paths running in an east-northeasterly direction. The first and longest, and the one which accounted for severe damage to the village of Colfax, was 35 miles long, and although characteristically narrow over most of its extent, eventually widened into a 1½-mile path of almost total destruction. Each successive tornado of the system began to the south of the previous one, and at about the time the latter was reaching the end of its course. The second of the series produced a somewhat shorter path of about 17 miles, but was equally violent and caused severe damage to the northern outskirts of the city of Chippewa Falls. The paths are shown in figure 1.

2. DAMAGE PATTERNS

The damage patterns were recorded by a series of aerial photographs obtained with the assistance of Prof. Gilbert Tanner of the Wisconsin State College at Eau Claire. Some 130 photographs were taken along the paths of the first and second tornadoes of the system. Over large segments of the paths the forest cover was adequate to permit quite accurate reconstruction of the damage patterns, even though, in the intervening open fields, no sign of damage was recognizable from the air.

The first tornado of the series was sighted as it touched down at about 6 p.m. south of the village of Woodville. From visual reports it seems evident that at this stage the storm consisted of a distinct and typical tornado funnel. Almost immediately after reaching the ground it struck the wooded area shown in figure 2. Although the tornado's path was almost exactly centered over this wooded section, it can be seen from the photograph that damage was much more complete in the southern half (lower part of picture), where the storm's translational speed of about 50 m.p.h. was added to the rotational motion (and of course was subtracted in the northern half).[2] A reconstruction of this damage pattern and those immediately following is shown in figure 3, where arrows represent fallen tree directions. In many instances the trees lay crossed over one another, as indicated in the sketch, and

[1] Somewhat similar patterns were recorded in Europe by J. Letzmann [1].

[2] See a discussion of this effect by G. W. Reynolds [2].

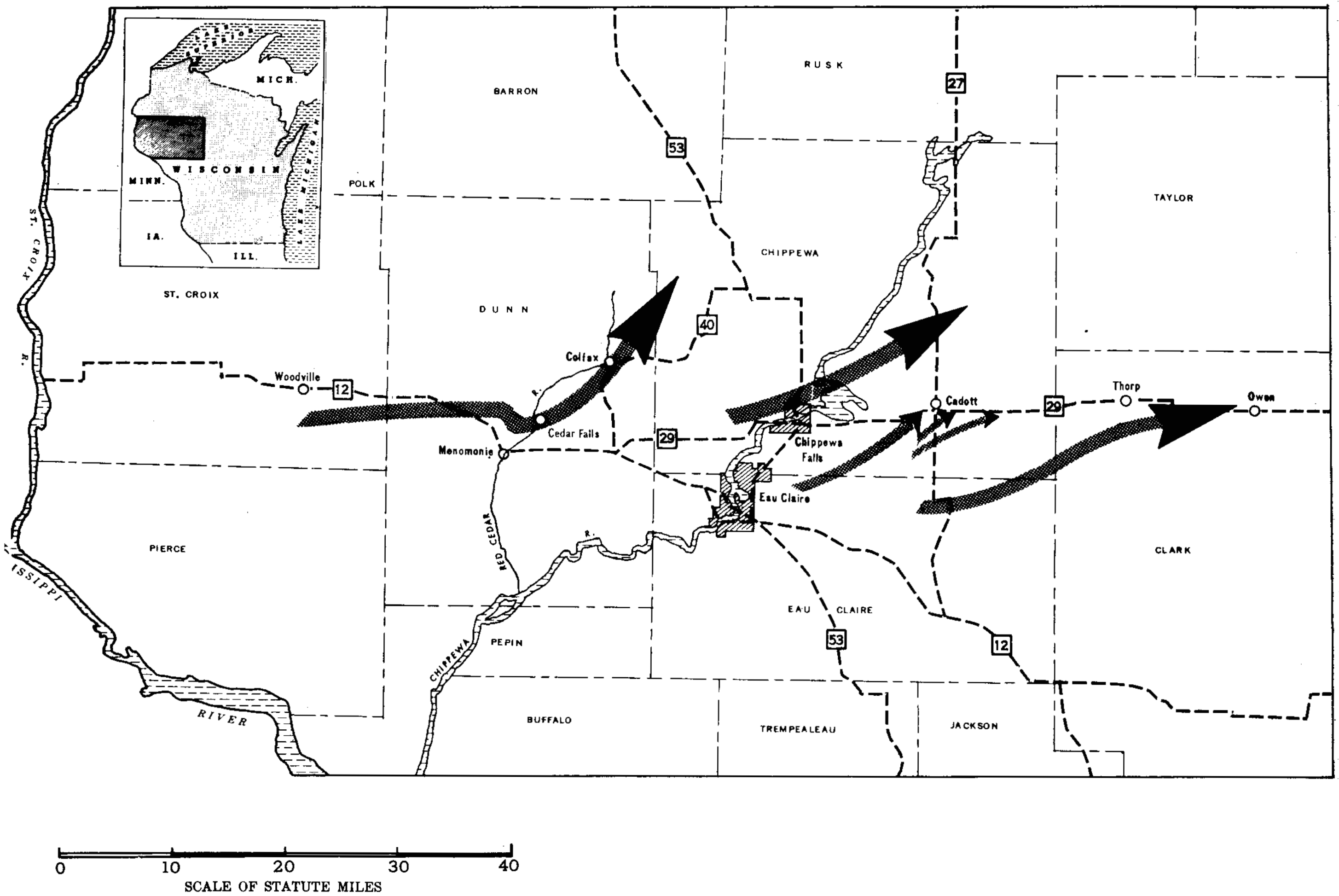


FIGURE 1.—Paths of major tornadoes of storm system.

in all such cases the sequence of directions in which the trees fell corresponded to what one would expect from the passage of a compact cyclonically rotating vortex. As can also be seen, the "reverse" flow along the northern side of the path became much less prominent as the storm progressed, suggesting that rotation had slowed somewhat so that the translational speed was more effective in countering the backward-moving component, or that the translation was much faster. This feature was an early indication of the highly variable character of the storm patterns which was typical of the entire track.

Pronounced damage patterns were infrequent for the next 8 miles of the path, and the storm may have been on the ground only intermittently or may have missed most of the heavily wooded areas. However, at about mile 7 another wooded tract was struck, apparently head-on, and again the pattern, as can be seen in figure 4, leaves unmistakable evidence of a well-formed and classical tornado funnel.

Between miles 11 and 16 the character of the pattern seemed to change. There was almost none of the marks of a rotating core that had been obvious earlier. Rather, the predominant feature was what might be called a "herringbone" pattern, with the fallen trees directed forward and inward toward a sharp line of separation (at this line the trees sometimes even crossed each other on falling). The reconstructed damage patterns along this portion of the path are given in figure 5. Such patterns suggest the passage of a fast-moving center of strong inflow or convergence, with only a faint suggestion, on the northern side of the path, of the "reverse" flow associated with a funnel.

Continuing along the path, the pattern of the next few miles (roughly miles 17 to 19, fig. 6) returned to the general appearance of that seen in the later part of figure 3, where a strong forward flow along the southern edge of the path accompanied a rather weak and confused reverse flow along the northern edge of damage, all suggestive of modest rotational speeds coupled with pronounced forward movement. But beginning at mile 19 and continuing through mile 21 the full rotary pattern again became well marked, presumably due to an increase in vortex speed or to a slowing down in forward motion, or to both. The reconstructed damage pattern for this segment is given in figure 6. Not only did the pronounced rotation reappear, but the path showed an abrupt change

FIGURE 2.—Damage pattern in forested area where tornado first touched down.

in direction. As one explanation, the funnel may have continued toward the northeast, but then turned sharply southward and thence back on an eastward course. Alternatively, the original funnel may have dissolved as it moved northeastward, to be replaced by another forming to the south, as was the case on a much larger scale with the individual storms of the system, as mentioned earlier. Figure 7 is a photograph of the destruction which occurred at point "A" of figure 6, and illustrates the circularity of the pattern. Also significant here is the sharp demarcation between destroyed and undamaged forest.

After thus deviating in its course, the storm crossed the Red Cedar River and struck the village of Cedar Falls, then continued its march to the east-northeast toward Colfax, some 8 miles distant. The area here is intensively farmed and the infrequent wooded sites in the storm's

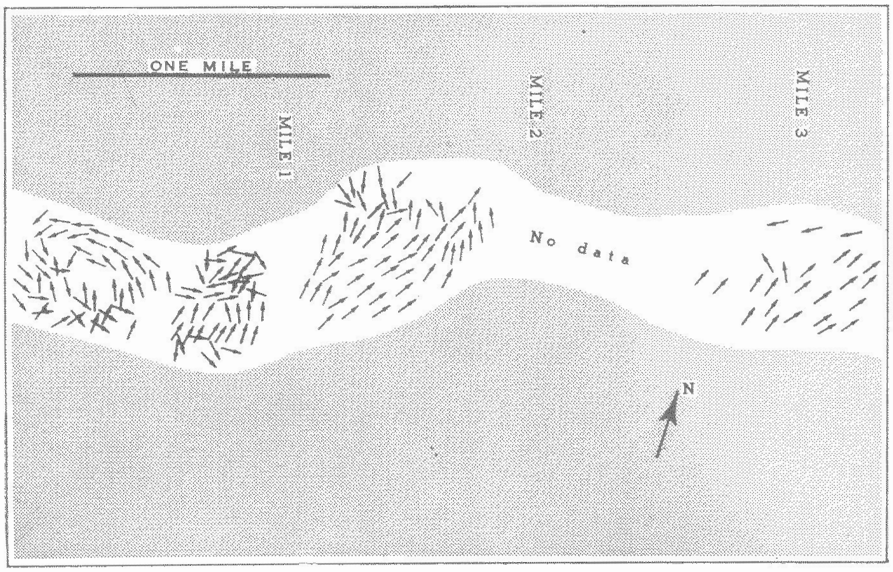
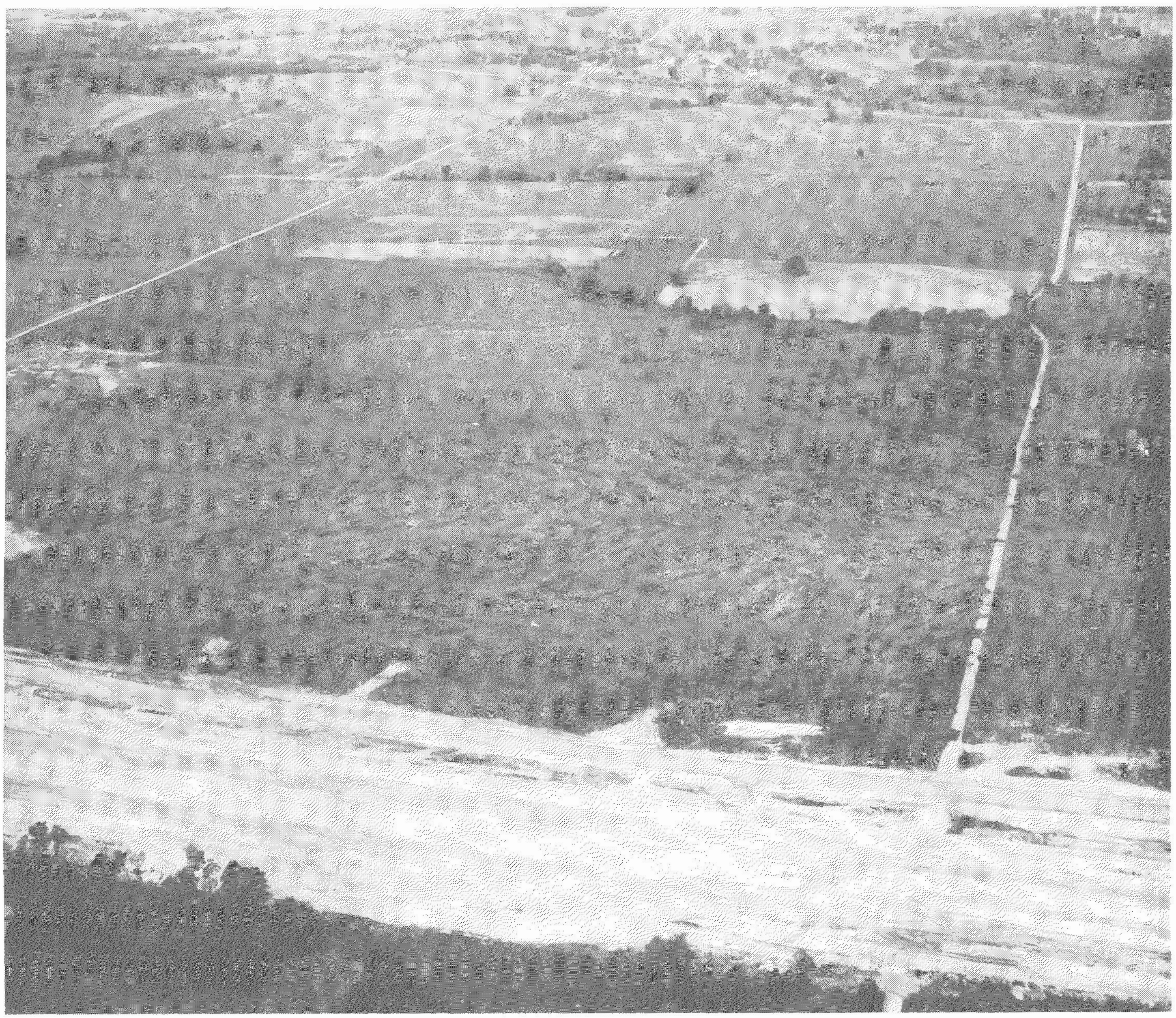


FIGURE 3. (At left)—Reconstructed damage pattern over first segment of tornado path. Arrows represent fallen trees.

FIGURE 4. (Below)—Damage pattern showing distinct circularity.



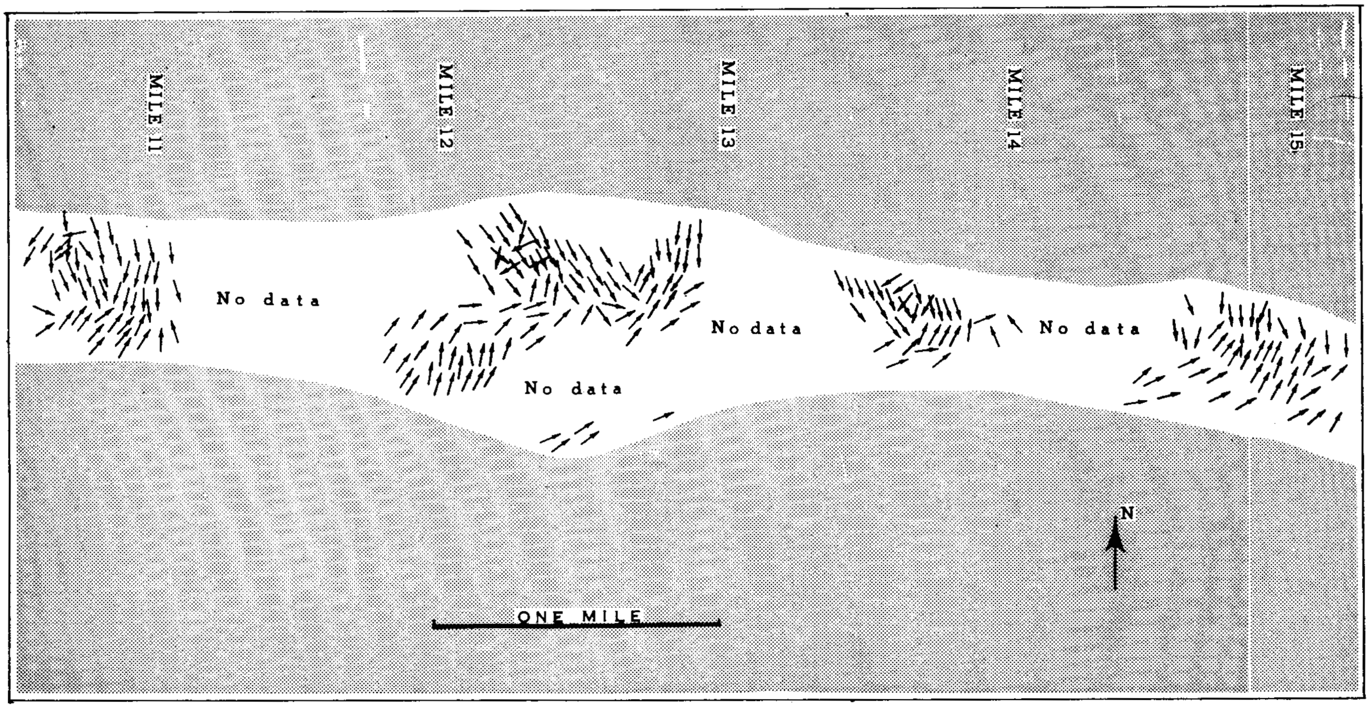


FIGURE 5.—Reconstructed damage pattern of the "herringbone" type.

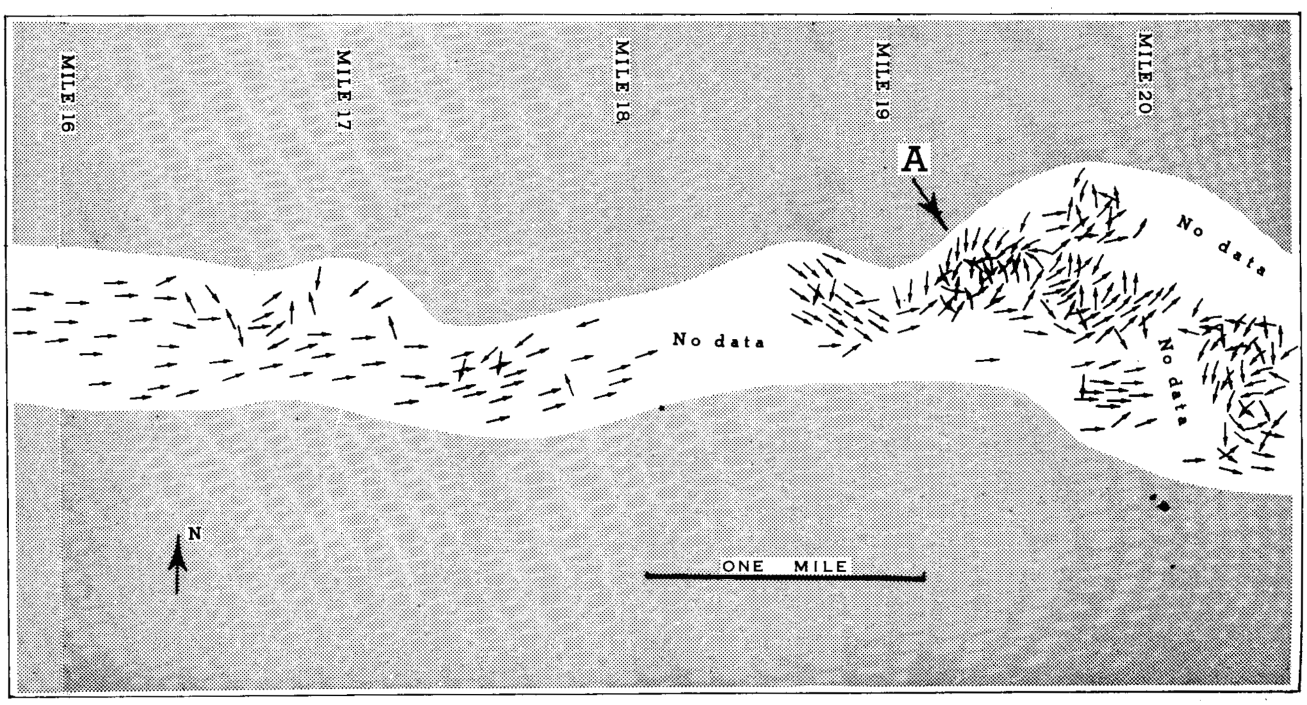


FIGURE 6.—Reconstructed pattern near midpoint of path.

FIGURE 7.—Circular pattern at point "A" of figure 6. Note sharp demarcation between damaged and undamaged trees.

path were, with two exceptions to be mentioned later, inadequate to define a clear-cut damage pattern. At this time, however, the storm was described by witnesses, not as a classical funnel, but rather as a huge bowl-shaped protuberance about half a mile wide, that extended to the ground from the low cloud deck of the squall line with which it was associated. Heavy rain preceded and accompanied the storm passage during this period.

The last 6 miles of the storm's path (miles 29 to 35) are pictured in figure 8. The shaded area is the built-up section of the village of Colfax, the southeastern one-third of which suffered almost complete destruction, with widespread but more irregular damage elsewhere. Perhaps the most impressive feature of the patterns is the sharp line of demarcation between the opposing flows from the north and from the southwest. From place to place along this line can also be noticed the confused and at times circular patterns characteristic of high-speed vortex motion. Substantial alterations in pattern as the storm progressed are quite noticeable and might indicate highly

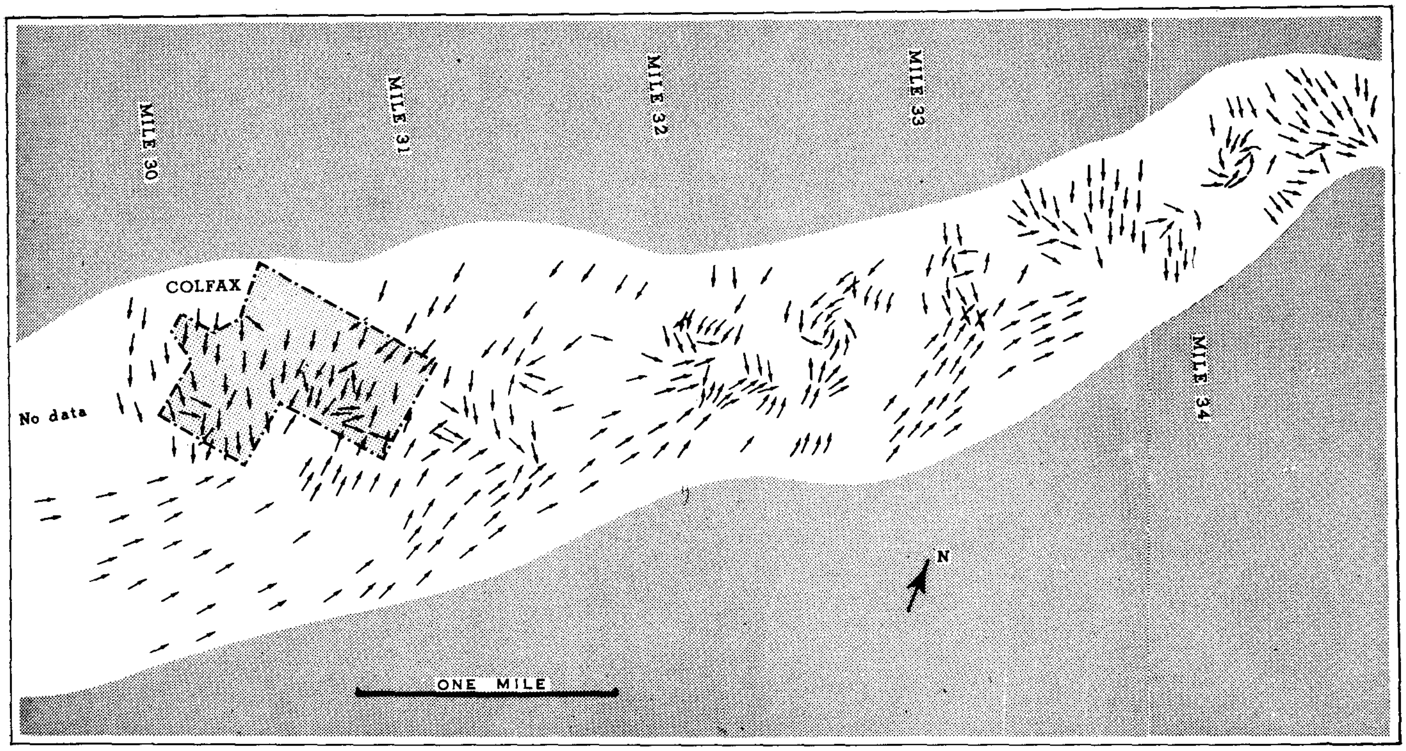


FIGURE 8.—Reconstructed pattern of final portion of path. Built-up portion of village of Colfax shaded.

unsteady storm structure, except that here the terrain is quite rolling or even hilly, and may have been sufficient to distort the flow. Taken as a whole, however, the patterns suggest a central high-speed funnel or vortex surrounded by an intense cyclonic circulation giving destructive winds out to a radius of ¾ mile. The highly convergent appearance of the damage also suggests, however, the presence of intense inflow toward the center of the storm sufficient to distort the pattern normally produced by a moving rotary system of winds. Figure 9 shows a view of Colfax, looking northward from the southern village limits.

3. FLOW MODELS

Three idealized flow models were constructed to see how well they might account for the actual damage patterns. These consisted of—

(*a*) a translation speed of 25 m.p.s. (56 m.p.h.) combined with a VR vortex in which the winds were set at 55 m.p.s. (123 m.p.h.) at a radius of 100 m. from the center and decreased in proportion to increasing radius;

(*b*) translation combined with a sink with converging wind of 60 m.p.s. (134 m.p.h.) at the 100 m. radius and decreasing with increasing radius in the same fashion;

(*c*) translation combined with both vortex and sink (this of double the above strength).

The sequences of winds which would be experienced at the surface during the passage of these systems are shown in figure 10. Model (*a*) would undoubtedly account for the patterns of both figure 3 and figure 6, where rotation and translation seem predominant and the degree of "circularity" of the pattern would depend upon the forward speed of the system relative to the intensity of the vortex circulation. Thus the strongly circular patterns at the beginning of figure 3, where the tornado first touched ground, and at point "A" of figure 6 imply high vortex speeds or low forward motion. In the first case it seems possible that the funnel may have built up to very high speed just before touching the ground. Then due to surface friction this speed may have been reduced to give the translational type of pattern immediately following and continuing for the next mile or two. In the case of the circular patterns of figure 6, a marked deceleration of the system would seem likely, accompanying the change in direction or alternatively in connection with the substitution of a second funnel for the first. This furnishes a possible explanation for the recurrence of circularity, but does not necessarily account for the sharp demarcation between damaged and undamaged forest noted in figure 7. The latter suggests the funnel was more in the nature of a spinning column of air, perhaps in solid rotation, moving through a relatively undisturbed environment not partaking of the tornado circulation. It is possible that this particular vortex was indeed dying out, as suggested prexiously, and was merely "coasting," separated from the VR circulation which was then attached

FIGURE 9.—View from south of part of damage at Colfax, Wis.

to the newly developing funnel. Behavior similar to this has been observed in the past where little wind has been felt immediately outside the funnel itself.

Model (*b*), representing strong inflow toward a moving center (implying a major sustained updraft into the storm center), seems consistent with the herringbone damage patterns of figure 5, where the survey found no significant evidence of rotation. If this interpretation is correct, the funnel must have been lifted off the ground accompanying a resurgence in cloud formation taking place at or near the storm center. An unbalance between pressure gradient and winds, perhaps caused by friction, may have resulted in strong upward motion around the funnel, pulling it upward—possibly the same mechanism responsible for the formation of the "collar" or "ruffle" near the cloud base noticed in several other tornadoes.

The final stage of the storm's course, as illustrated in figure 8, seems to differ substantially from the earlier patterns, and is most closely approximated by the three-way combination of rotation, translation, and inflow of model (*c*). This model appears to explain the flow from the southwest along the bottom of the path separated quite sharply from the flow from the north along the upper portion. A number of observers in this portion of the storm path reported marked wind shifts as the storm approached closely. At first, winds were from an easterly direction, with enough force to blow over smaller trees. A few seconds later the main storm struck with winds from a southwesterly direction, and with much greater force. Such a sequence would not be compatible with

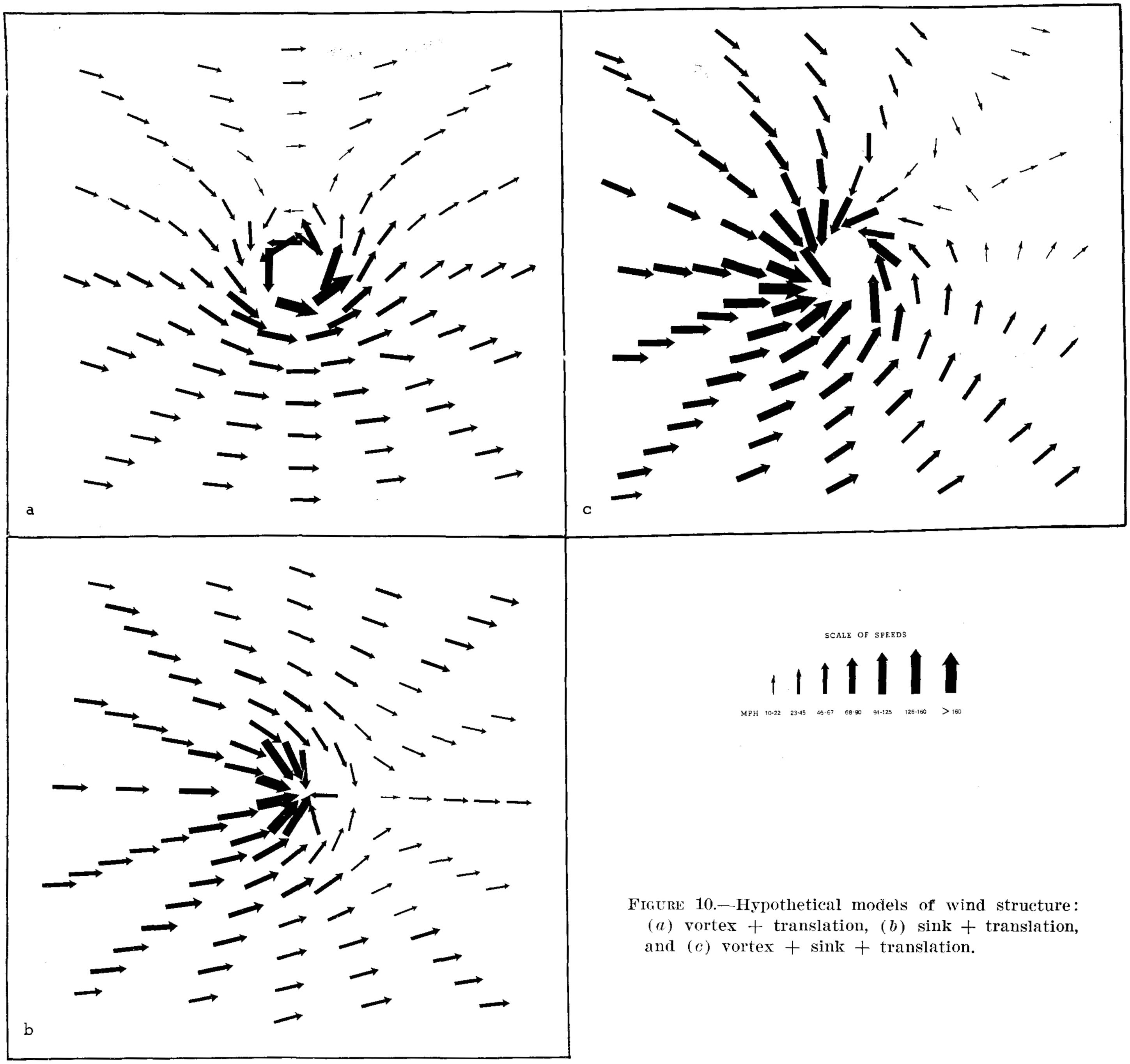


FIGURE 10.—Hypothetical models of wind structure: (*a*) vortex + translation, (*b*) sink + translation, and (*c*) vortex + sink + translation.

model (*a*), but might very well occur with models (*b*) and (*c*) near the axis of motion, provided the final inflow speeds greatly exceeded the translational and rotational speeds. Thus, due to the high rate of inflow, the wind would blow back toward the approaching center for a brief period before the center passed, to be followed, south of the center, by strong flow in the direction of general storm movement.

The unsteady state of the storm during this final stage is evident from the variability of damage patterns shown in figure 8. For this reason no one hypothetical model can be expected to provide an exact "fit" to the observed patterns. Also, as has been mentioned, the rolling and hilly topography in this section may have had a decided influence on resulting damage by producing distortion of the wind flow.

A flow pattern of quite different character is illustrated in figure 11, which shows a distinct fan-shaped or "crow's-foot" distribution of felled trees. This pattern occurred at mile 26, and a similar one occurred a mile earlier. Over

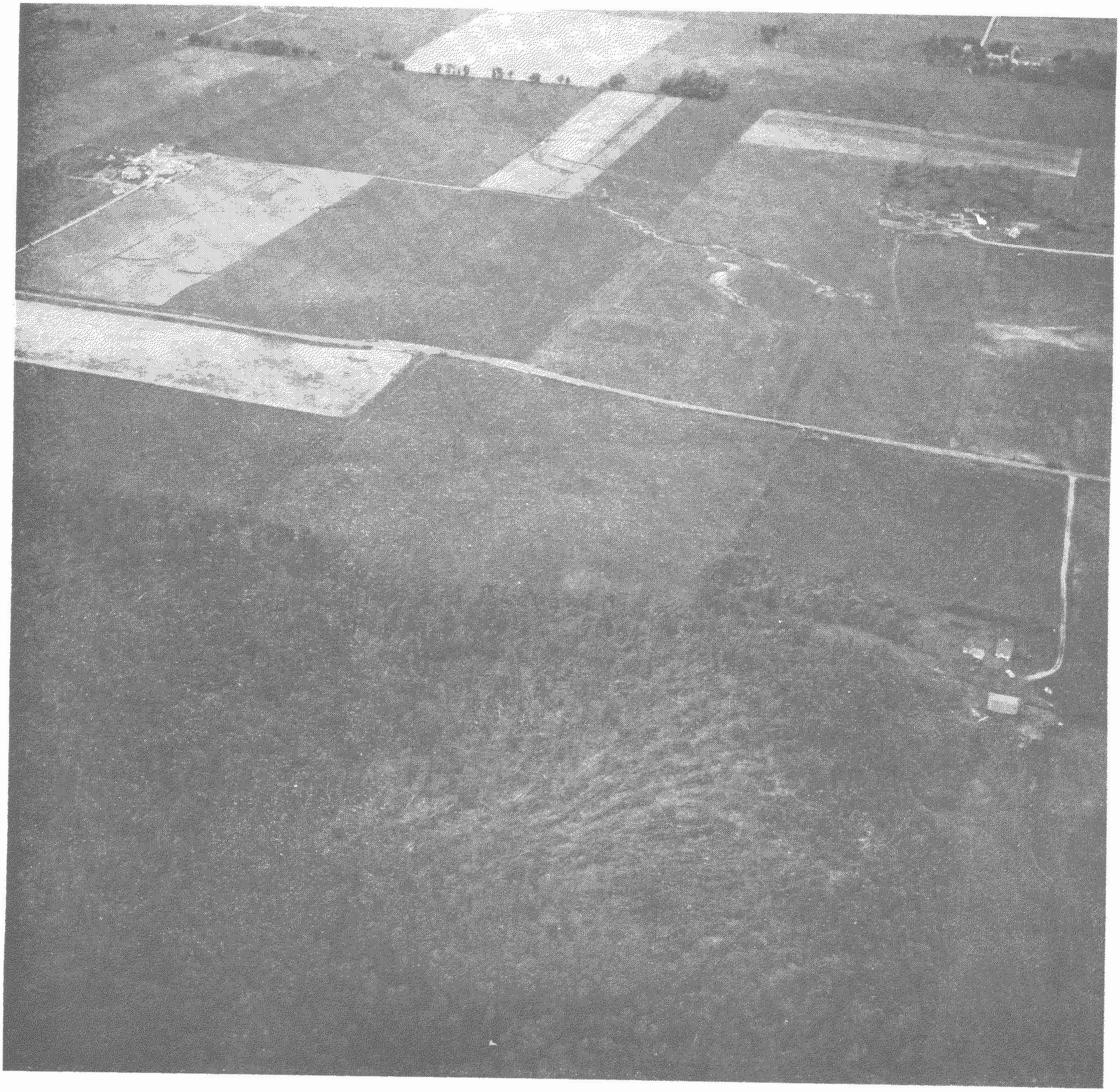


FIGURE 11.—Fan-shaped damage pattern.

level terrain one would undoubtedly conclude that such a pattern was produced by a combination of a source (downdraft) and translation. In both of these cases, however, the pattern occurred on hills (wooded portion in fig. 11), leaving the possibility that it was due to the terrain.

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